

The Clinical Aspect of Chronic Poisoning by Aluminium and its Alloys

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LONDON

JOHN BALE, SONS & DANIELSSON, LTD.
83-91, GREAT TITCHFIELD STREET, W.1

1933

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A COMPARISON of the incidence of gastro-intestinal and metabolic disturbances as observed amongst the population in certain parts of the Continent¹ up to ten years ago, with that in England during the subsequent years, soon showed that the population of this country appeared to be suffering with greater frequency and in much graver degree. The methods of treating these diseases applied successfully abroad proved, in many cases, to be ineffective here, and an opportunity to investigate the reason for this came when I myself, hitherto in perfect health, became a victim to chronic disease.

In the following a symptom-complex will be described as observed on a large number of patients, including myself. The self-observation, perfectly objective and reliable as it was, helped to eliminate such symptoms, described by patients, as appeared to be inaccurate or misleading in comparison with my own. On the other hand, this self-observation helped to correlate the statements made by patients with the symptoms from which I myself was suffering.

Three main groups are distinctly discernible, namely : *gastro-intestinal, cutaneous and general.*

In the first group the outstanding feature is *constipation*. It appears that this complaint is present in almost every patient, and even amongst those who do not suffer from it habitually, it is present from time to time. Few are found who are not obliged to use an aperient, however small the quantity. Constipation is invariably accompanied by *flatulence* and *colicky pain* of such

¹ Austria and Czecho-Slovakia.

severity as in some cases to suggest the possibility of gastric or duodenal ulcer, cholelithiasis, nephrolithiasis, colitis or even "acute abdomen," and resistance of the abdominal wall associated with tympanites appears to be extremely common. Some patients complain of *dryness in the mouth and throat*. The *appetite is considerably impaired* or entirely lost and there is *retching* during or after meals, with, in some cases, a distressing *hiccough*. Attacks of *nausea* set in and, in more advanced stages, also *vomiting* of every kind of food soon after it has been taken. X-ray examination reveals in these cases only colonic stasis.

The obvious change presented on examination concerns the *condition of the mouth*. The tongue loses the natural aspect of a flesh-coloured, moist, smooth surface, with the papillæ vallatæ and foliatæ only slightly elevated. There appears a *thick white or dirty grey fur*, with the papillæ vividly red and enlarged. The patients at first attribute this condition of the tongue to a slight attack of indigestion, caused previously by some article of food. The changed appearance, however, persists, and different methods of treatment, dietetic as well as mechanical, fail to remove the fur. The only method which temporarily restores the normal aspect appears to be scraping the surface with a soft tooth-brush dipped in bicarbonate of soda. This action seems to be chemically neutralizing rather than mechanical.

Later on, in much advanced cases, the tongue becomes indented by the teeth, raw and excoriated. Deep fissures appear on the surface and constitute the condition of *superficial glossitis*.

In acute exacerbations the whole mucous membrane of the mouth is involved and presents the complete picture of *stomatitis*. Herpetic ulcers develop and the gums appear red and swollen, with pus collecting under them, and thus a condition of severe *gingivitis* closely similar to, if not identical with, *alveolar pyorrhœa* is established.

In the meantime, the initial gastro-intestinal symptoms progress steadily towards a chronic condition, in spite of most careful dieting.

Certain *skin conditions* also appear to be present with greater frequency in this country than they were on the Continent up to ten years ago. *Acute and chronic urticarias*, and the various *eczemata* usually attributed to idiosyncrasy for certain foodstuffs occurred but rarely in my continental experience. In this country, on the other hand, in the acute cases the signs and symptoms are often of such unusual severity, as immediately to suggest their being due to a highly potent irritant which, in its action, is closely similar to arsenic and belongs probably to the same group of poisons, although arsenic itself has not been found. Cases of *pruritus* generalized all over the body, of unknown origin, appear also to be extremely common. Sometimes it is more pronounced in the hands and feet, and especially in the interdigital spaces. In more advanced cases a skin disease develops, which, when affecting the fingers and hands, is diagnosed as *cheiropompholyx* and *dysidrosis* and generally attributed to a *vasomotor neurosis*, the lesions being in anatomic relation with the sweat-structures. Between the toes, and more especially in the third and fourth interdigital spaces, a condition makes its appearance which is very similar to, and in fact is often diagnosed as, "*dhobi-itch*" or "*foot-tetter*," if a fungus is found. Excoriations and *rhagadæ* between the toes develop, and a normal skin in the interdigital spaces showing no peeling is hardly ever seen. Very often, however, no fungus can be detected by any method and then the condition is diagnosed as being due to gout or to so-called "*soft corns*." In some cases the skin of the whole or parts of the body is affected by a rash which, when attacking children, is identical with "*infantile eczema*" and often attributed to allergy. In other cases recurrent attacks of *herpes* situated on any part of the body, or

the occurrence of persistent *furunculosis*, are a striking feature. Scattered over the skin of the chest and abdomen, multiple pin-head or larger sized *telangiectatic nævi* are often observed. Loss of hair, keratosis of the palms and soles, and so-called "chilblains" on the fingers and toes are met with quite frequently. *The finger nails become soft and brittle*, lose their lustre and appear opaque and thickened, while longitudinal striation in varied degree is usually present. When associated with onychia and paronychia, their appearance is very similar to onychomycosis, but a fungus cannot always be detected.

Turning to the third group in the symptom-complex, frequent attacks of *neuralgicæ and twitching of the legs* must be mentioned. They occur mostly at night during sleep, and are sometimes so painful as to alarm the patient. Pain in the fingers and toes, *paræsthesicæ of the whole hands and more especially along the ulnar nerve distribution of the fingers, associated with the sensation of numbness and deadness*, in some cases even gangrene of the toes, resemble very much Raynaud's disease and ergotism. *Arthralgicæ* of the most severe type, diagnosed as being of rheumatic origin, are a very common occurrence. *Giddiness and excessive perspiration* are frequently observed and *anæmia* is a regular feature. In the urine, traces of albumen and a few red blood corpuscles can be found, and the regularity with which *a slight reduction of Fehling's solution* is detected in practically every patient, often perceptible only after the tested material has cooled down, is most remarkable. *A systolic blood pressure as low as 80 mm. Hg.* among middle-aged and even older patients is met with very frequently. Nervous symptoms comprise *depression*, and even melancholia, loss of energy and general lassitude.

It must, of course, not be assumed that all the symptoms are in each case developed to the marked degree

which has been described, or that they run concurrently in every patient. In some patients a few or all symptoms of one group, for instance, gastro-intestinal or cutaneous, predominate. Others may complain at one and the same time of symptoms described in two of the groups given above, for instance, gastro-intestinal and cutaneous.

These latter, however, or even those suffering from all the three groups, were met with so often that a common cause suggested itself as ætiological factor. It was curious that patients who left England temporarily to live abroad improved in health rapidly, even without any medical attention, and that they suffered from recurrence of their symptoms within a very short time of their return. On the other hand, people with previously perfect health who came to live in London complained of illness after a stay of a few months, or even weeks. It was therefore to be suspected that the causal agent must be looked for in this country, and some of the cutaneous manifestations, when accompanied by symptoms of the other two groups, were chosen as a starting point of the investigations.

It has already been mentioned that the dermatoses under discussion were attributed in many cases to a vegetable fungus, which, however, could frequently not be detected. Where a fungus was found, local treatment often failed to cure the condition. If these dermatoses were actually due to infection, then, it was thought, severe gastro-intestinal disturbances occurring at the same time might likewise be caused by the same or a similar fungus, introduced into the body by food or fluid contaminated by it, thus constituting a mycotic gastro-enteritis. The food would have to be such as was most indispensable in everyday life, since patients suffering from these groups of symptoms belonged to different spheres of life and lived in different parts of London. Bread and its ingredients, meat, milk and butter, vegetables, fruit, coffee, tea, sugar, salt and water had to be considered.

The empiric method of elimination was chosen for the investigation. One article of food after another was struck off the list of diet, and it was recommended that water be taken only after being boiled. The results, however, were always negative, and it was concluded that experiments in this direction were fruitless.

To make certain that water could not be suspected of contamination, the cisterns in my house were emptied and cleaned under my personal supervision. Contrary to expectation, only a mineral, and no organic matter visible to the naked eye, was found, and thereupon the theory of an organic poison was given up and the possibility of the presence of a mineral or metallic poison accepted. This again led to the belief that the symptoms might be traced back not to the different articles of food, *but to the utensils in which this food was prepared.*

From the fact that all the cooking utensils used in the house were made of aluminium, attention was especially directed to the possible occurrence of a poison therein. This suspicion had to be maintained for the particular reason that subsequently, in several cases, *lead* was found in the excreta, and in some *tin* as well.

To keep aluminium utensils clean, soda or a material containing it, such as soap, special cleaning powders, etc., are used. For the sake of experiment the aluminium utensils were not removed altogether from the household, but the order given that instead of cleaning them with soda, only water and brush should be employed, with the result that not only the rebellious skin disease diagnosed as cheiropompholyx and dysidrosis and the affection very similar to "dhobi-itch," but also all the gastro-intestinal symptoms came to a standstill within a few days. The improvement was still more marked when the aluminium utensils were removed altogether. It must therefore be assumed that all the symptoms were due to a poison contained in the aluminium utensils.

At this point emphasis is laid on the fact that nothing was known to me at the time (i.e., 1928) in regard to the discussion in the medical press of different countries about the possible toxicity of aluminium. The literature concerning this metal was gone into only after the above conclusions were arrived at, and it showed that a dispute had been proceeding for many years and had led, in some cases, to a controversy between the medical profession and powerful industrial interests.

It is true that the described condition was not *entirely* cured by the elimination of aluminium utensils. Although the cutaneous manifestations disappeared altogether, the gastro-intestinal symptoms, though considerably alleviated, persisted in appearing shortly after meals. The possibility of the presence of some additional irritant had therefore to be pursued, with a view to finding further sources containing injurious substances, such possible sources being tinned foods and hard aluminized or chlorinated tap water, running through lead pipes, to which attention had again to be directed.

A diet was now chosen which excluded everything prepared in tap water. Only raw fruit, or fruit and potatoes baked in their jackets, soft-boiled eggs, etc., were given, and tap water replaced by a pure and wholesome natural mineral water, which was also used for boiling food wherever possible.

To adsorb and eliminate the poison accumulated in the body, large doses of a high-grade charcoal and an aperient were given.

This régime was applied with the strictest perseverance in all the cases included under the three headings given at the beginning of this paper, *and it resulted in the most rapid disappearance of all the symptoms, including the skin manifestations.* A complete cure, not obtainable by any other of the many methods of treatment applied hitherto, was maintained as long as the patients persevered with the régime prescribed to them. They were put gradually on an ordinary diet, but were not allowed to use aluminium utensils, tap water or other

likely sources of metallic contamination, and remained perfectly well as long as they took small doses of charcoal and an aperient. In cases, however, in which for some reason they omitted these precautions, the symptoms again made their appearance, to disappear as rapidly as before, when the régime was again strictly followed.

CONCLUSIONS.

- (1) The extremely common manifestations of the skin, such as pruritus, dermatitis herpetiformis, cheiropompholyx, dysidrosis, infantile eczema, etc., *are of gastro-intestinal origin*, and accompanied by gastro-intestinal symptoms and those of disturbed metabolism.
- (2) The symptom-complex described is caused by one or several irritants contained in aluminium utensils and in chlorinated or aluminized tap water, since it disappeared when further intake of poison was stopped and the amount ingested was eliminated by charcoal and aperient.
- (3) As the skin manifestations disappear under the described treatment, without any local applications, it seems likely that the prevailing theory that they are caused by a fungus is not tenable. It is probable rather that this infection, where present, is of a secondary nature.

It is not proposed to illustrate any individual cases which suffered from chronic poisoning by aluminium *without* involvement of the skin. *Their number was very large* and, while in general conforming to the above description, they presented a *varying degree of sensitiveness to the metal*. Illustration of these cases is omitted, since it might be suggested by sceptical critics that the cure claimed in such cases of long-standing gastro-intestinal and metabolic disturbances was due to psychological effects. It may, however, be accepted as a fact that all these cases improved within

a very short time, often not exceeding three weeks, after the commencement of the treatment described.

The absolute correctness of the conclusions arrived at cannot, however, be demonstrated more clearly than by citing a few of those patients, including myself, who exhibited, in addition to the other two groups of the symptom-complex, *preponderately cutaneous manifestations of poisoning by aluminium*. As a matter of fact, the digestive trouble in some of these cases was sometimes relatively slight and often overlooked by the patients, owing to their preoccupation with the condition of the skin.

(1) My own case of cheiropompholyx was unsuccessfully treated for about a year by every conceivable local method. Treatment on the lines suggested effected a complete cure within about four weeks. A few other cases of this disease and also of dysidrosis of up to seven years' duration reacted in precisely the same manner.

(2) A girl, aged 11, had been suffering from infantile eczema, *diagnosed as of allergic nature*, practically since birth. The skin was even then unusually dry, and the medical man in attendance thought the child would probably never have a normal skin. The actual eczema made its appearance at the age of one month. Continuous local treatment suggested by different dermatologists proved to be ineffective and the child had to be kept permanently in bandages. In fact, for some years splints had to be used to prevent it from scratching. The local applications succeeded only for a short time, in alleviating the pruritus. Apart from such short intervals the misery of the child's life and that of the family was said to be beyond description.

(3) A boy, aged 5, had been the victim of the same disease for four and a half years. Local treatment given by various skin specialists failed to have the slightest effect, and the child, always covered by bandages, could not be shown to the relatives. The itching was so intense that the child used to fall asleep only from

exhaustion and wake up again at frequent intervals.

(4) A boy, aged 4, had the same disease in a slighter degree than the two previous cases, but sufficiently to prevent the parents from interrupting local treatment even for a short time.

The children were put on a diet, not different in any respect from that given to a normal healthy child, with the exception that food was not allowed to be prepared in aluminium utensils. In addition, care was taken that besides this metal the ingestion of any other metallic substance contained in tinned foods, chlorinated and aluminized tap water running through lead pipes, etc., was stopped. To adsorb and eliminate the poison accumulated in the body a high-grade charcoal was given in large doses, followed by an aperient. *All local treatment was discontinued.*

The result of this régime proved successful in all three cases. The first child was practically cured in five weeks. The second, after ten weeks' treatment, remained entirely free for two and a half years, when the parents, believing the child now out of danger of susceptibility, gave him food not subjected to the above-mentioned restrictions and the condition recurred. On resumption of the treatment the skin again healed. The slighter eczema of the third child disappeared after three weeks' treatment on the same lines. When food was given which was not free from metallic contamination the eczema soon recurred, to disappear as rapidly when the régime was again strictly followed.

(5) Amongst several cases of acute urticaria one man was suffering from attacks for a year. They were of unusual severity and the wheals as large as the palm. When affecting the scalp and ankles, their circumference increased to such a degree that the patient was unable to put his hat on or to lace his shoes.

(6) A man, aged 74, suffered for many years from chronic urticaria which prevented him from having a full night's rest. The severe pruritus resulted in scratching effects distributed all over the body.

(7) A man, aged 62, with persistent furunculosis was treated by every conceivable method for 6 months without the slightest benefit.

These cases are only a few examples chosen from a great number of patients who, having suffered for a long time from the mentioned skin affections, for which no further remedy could be found, readily acceded to any new line of treatment suggested to them. In all these cases a complete cure was achieved by the described method in the course of a few weeks.

In an attempt to arrive at conclusions with regard to the irritant or irritants suspected as present in aluminium utensils, it will be useful to describe the materials employed in their production.

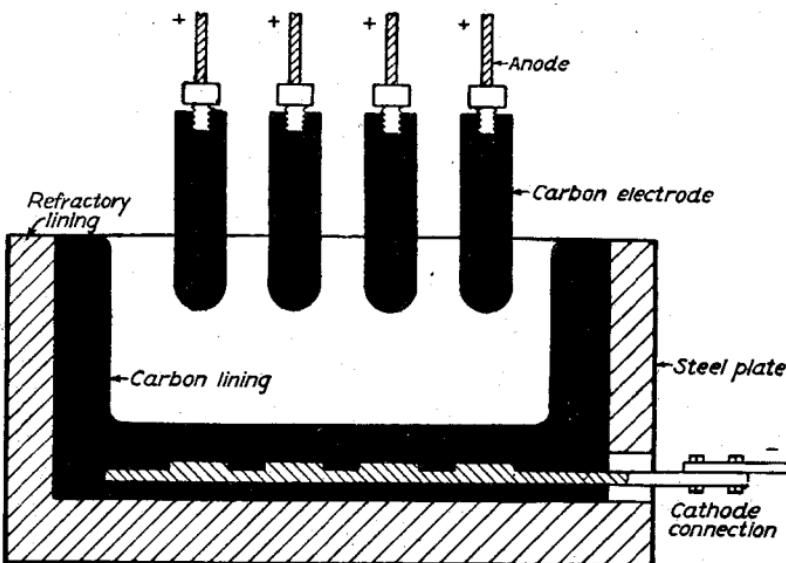
In the manufacture of the metal, the first essential raw material is a mineral containing aluminium, which is found mainly as the hydroxide in *bauxite* and as the fluoride in *cryolite*. In the commercial production of the metal, only these two aluminium minerals are utilized.

Bauxite ore is an hydrated oxide of aluminium, corresponding to the formula $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$, mixed with various impurities, chiefly iron oxide, silica, clay and titanium oxide. The range of its composition is wide, and at the present time bauxite carrying less than 50% alumina (Al_2O_3) and up to 7% silica (SiO_2) is used. After a preliminary wet chemical treatment it forms the base ore from which alumina is prepared. This prepared alumina is then fed to the aluminium cell.

The usual furnace consists of a rectangular box of mild steel, lined with a refractory material of low thermal and electrical conductivity and within this a heavier lining is made of rammed carbon, forming the cathode. *This carbon lining is made of petroleum coke, with a suitable oil or tar binder rammed in place.* The composition of the anodes is the same as that of the lining (cathode). They contain iron and silicon as

impurities which must be removed as much as possible, lest they make their final appearance in the aluminium. *The consumption of the carbon is, roughly, 0.7-0.9 lb. of anode for each pound of aluminium produced.*

The next essential for the production of the metal is cryolite, an aluminium mineral of the composition Na_3AlF_6 (or $3\text{NaF} \cdot \text{AlF}_3$). It is the chief constituent of the electrolytic bath used to dissolve the alumina. After purification it contains roughly 30% sodium, 50% fluorine, 12-13% aluminium, 0.25-0.50% silica and 0.1% iron. The high price of natural cryolite



Sketch showing construction of modern aluminium-reduction cell.
Reproduced by kind permission from page 113 of R. J. Anderson's
"The Metallurgy of Aluminium and Aluminium Alloys."

has led to the production of the synthetic compound and this artificial cryolite, which is at present widely used, contains more fluorine than the natural mineral, namely four molecules NaF , as compared with three molecules NaF . It is produced by treating hydrated alumina and sodium chloride with hydrofluoric acid. Although it is more easily decomposed by the electric current than the natural mineral, it is now preferred in practice.

The alumina gained from the bauxite is now dissolved in the furnace in the liquid bath of cryolite, to which other salts, calcium and aluminium fluorides, have been added. The mass naturally comes in direct contact with the carbon of the cathode and with that of the anodes suspended in the bath. A large direct current is now passed through the bath and the dissociation of alumina into aluminium and oxygen is effected.

The product of the reduction cell, after remelting, appears on the market as "primary" aluminium, and this is graded according to the amount of impurities present. The chief impurities are said to be the following: iron, silicon and copper, alumina; and carbides, sulphides, sodium, nitrogen and titanium. The analysis of a sample of aluminium, said to be so pure as to contain more than 99% of aluminium, shows impurities amounting to a trace (up to 0.2%) of copper, 0.25-0.60% iron, and 0.15-0.40% silicon. Other samples, less pure, contain also lead and tin. This so-called "substantially pure" or "primary" metal is made into aluminium sheet by drawing and spinning operations and used for the manufacture of kitchen cooking utensils.

These are, however, produced not only from the "substantially pure" aluminium sheet. Aluminium-bearing scraps are again remelted, *but at this process no refining can be done*, and consequently this so-called "secondary" aluminium contains more impurities than the "primary" material, these usually including copper, iron, silicon, manganese, zinc, lead and antimony.

Moreover, for the manufacture of kitchen utensils sand-cast alloys of either the "substantially pure" or the "secondary" aluminium are also used. The possible number of aluminium alloys is almost limitless and includes those with copper, iron, magnesium, nickel, tin, zinc or a combination of these metals. From the manufacturers' point of view it has been found that the 95:2.5:2.5 aluminium-copper-silicon alloy is better than any other. As a matter of fact,

the sand-cast cooking utensil is preferred by the trade to the spun product because it has the appearance of durability and is more substantial.

DISCUSSION.

Having described the materials used in the manufacture of aluminium cooking utensils we can enter into the discussion of the mode of action of the principal element aluminium and some of the impurities contained in the finished article.

(I) ALUMINIUM.

The controversy concerning the dangers arising from its use is an old one, but the first classical experiments on animals were performed in 1886 by Siem under the direction of the well-known pharmacologist Hans Horst Meyer. When injecting small doses of sodium aluminium tartrate subcutaneously at intervals of a few days, he found that the animals died after 2-4 weeks, the lethal dose being an amount of the salt which corresponded to 0.25-0.30 g. (i.e., 4-5 grains) aluminium oxide per kilogram of the animal's weight. By injecting, however, a single large dose in cats, death resulted after only 5-10 days, the lethal dose being then as little as 0.15 g. (i.e., $2\frac{1}{2}$ grains) per kilogram.

The first symptom noted, as early as the third day after the commencement of the injections, was severe disturbance of the digestive tract. Anorexia, even complete refusal of food, and very severe constipation, with one single defaecation in the course of five days, were the outstanding features. With the cumulative action of the injections which were superadded at intervals, frequent vehement vomiting of bile-stained mucous masses and diminished excretion of urine developed. Albuminuria was not always present. Small ulcers appeared on the buccal mucous membrane and the animals lost weight rapidly. The blood pressure and the bodily temperature became low, owing to paralysis

of the centre of the nerve supply to the vascular system. Towards the end of the experiment the central nervous system became profoundly disturbed and the animals developed signs of acute bulbar paralysis. General tremor, with tonic and clonic convulsions of the head and extremities, accelerated death, which was due to paralysis of the respiratory centre, the heart being the ultimum moriens.

In the case of the cat, peroral daily administration of the salt corresponding to 0.1 g. (i.e., $1\frac{1}{2}$ grains) alumina per kilogram of the animal's weight for four weeks produced vehement diarrhoea, but with the beginning of the second week the animal again recovered its normal state.

The post-mortem examination showed hyperæmia and swelling of the mucous membrane of the stomach and small intestine, especially the duodenum, and small ulcers were found in the gastric mucosa. The kidneys were hyperæmic and deep red in colour and showed signs of parenchymatous nephritis. In some cases the cortical substance was much infiltrated by fat and exhibited a few pin-head sized extravasations of blood. The liver was dark red in colour but the outline of the lobules was quite distinct. The lobules themselves appeared opaque and slightly yellow. The heart muscle was invariably soft and flabby. Microscopically the liver showed finely granular degeneration and the vessels of the cortex and medulla of the kidneys were engorged with blood. The epithelium of the convoluted tubules showed signs of hyaline degeneration and their lumen was filled with hyaline casts.

Siem classes the mode of action of aluminium with that of mercury and lead, since all these metals are readily absorbed from the gastro-intestinal tract.

The ensuing controversy concerning the dangers arising from the use of aluminium compounds seems to have ceased for a time but was resumed once more in America before the War, when the question of the

aluminium contained in alum baking powder came under discussion. In this way the possibility of the aluminium contained in kitchen utensils being detrimental to health came to the fore. The discussion in medical circles in several countries, among them England, France, Germany, Switzerland and the United States, was protracted, *being chiefly concerned with the element aluminium alone*. As a result two sets of opinion developed which were diametrically opposed to each other. On the one hand the opinion has been expressed that, as the result of scientific investigation on animal and man, aluminium has been found to be innocuous. On the other hand, it was claimed with equal emphasis that scientific investigation had proved aluminium to be definitely poisonous. Between the parties were those who declared that although it was in general harmless, aluminium was found to be detrimental in some cases. Even the correctness of the methods employed in laboratory analyses and the value of the chemical and physiological experiments and pathological findings were disputed.

One set of investigators, amongst them Lehmann in Germany, Mackenzie, Schmidt and Hoagland, McCollum and his collaborators in America, stated that aluminium derived from artificially aluminized food was either not soluble and therefore not absorbed at all, or only in minute quantities which were perfectly harmless to the body, and that since there was no absorption there was no deposition of the element in the tissues. They contended that the amount of aluminium in aluminized food was very small in comparison with that taken regularly in the great variety of articles of food which contained it as a natural constituent. The sulphate of different metals was injected by Bertrand and Serbescu under the skin of animals, and they asserted that aluminium was less toxic than, for instance, nickel or copper, since an injection of 100 mg. (i.e., about $1\frac{1}{2}$ grains) of the aluminium salt

per kilogram of the animal's weight killed the animal only after 8·34 hours. The statement was even made by Myers and Mull to the effect that the injection of aluminium salts into animals raised their growth and reproduction. According to them, no abnormalities were to be noted in the animals at the autopsy and all the organs appeared to be healthy apart from a marked increase of the aluminium content in the liver.

Contrary to these findings, Gies, Steel and Kahn, all in America, found (each of them in independent investigations) that aluminium phosphate was dissolved by the hydrochloric acid of the gastric juice; that the aluminium chloride, thus formed, owing to its astringent and protein precipitating properties, attacked the mucous membrane of the stomach, passed from the alimentary tract into the blood circulation and, without manifesting any tendency to accumulate in the blood, was deposited to some extent in various parts of the body, whereas another part was excreted in both the bile and urine.

The conversion of aluminium phosphate into the chloride under the influence of the hydrochloric acid of the gastric juice was demonstrated in the excellent experiments made on animals by the French investigators Schaeffer and his collaborators. They too showed that aluminium was absorbed, in comparatively large amounts, into the blood circulation and deposited in the tissues of the body. Animals fed on aluminized food gained weight more slowly than control animals. The younger they were, the more sensitive were they to aluminium. They suffered from severe diarrhoea immediately after being fed on aluminized food, and showed a definite retardation of reproduction. The anatomical changes produced by aluminium were demonstrated by necrosis of the epithelium of the gastric mucosa in the region of the fundus and pylorus and also the duodenum, comparable with erosion seen in man; further by congestion and oedema of the mucous membrane of the intestine, especially the colon descen-

dens and the sigmoid. There was glomerulo-nephritis and considerable atrophy of the ovaries. All the control animals escaped injury.

In a very comprehensive series of experiments the American physiologists, Underhill and his collaborators, described the metabolism of aluminium. In animal experiments they found that the aluminium content in the blood tended to increase after ingestion of aluminized food. Aluminium was deposited in the various tissues and the main places of storage were the liver, kidneys, brain, spleen and muscles. The bile and spleen contained more than eight times, the brain more than five and a half times and the liver and kidneys more than four times as much aluminium per unit as the blood. On examining the tissues of dogs at different ages they ascertained that there existed a direct relationship between the age of the animal and the quantity of aluminium stored in the tissues, and that this same tendency for aluminium content to increase with advancing age existed in man.

In the clinical aspect of aluminium poisoning produced in experimental animals, loss of appetite was noted as the first symptom. They soon appeared inactive and depressed and lay quietly in their cages, manifesting no interest in their surroundings and, if forced to move, they were slow and clumsy. In addition, on feeding dogs for twelve weeks with aluminized food, a skin disease developed in one of the animals, which was covered with abscesses that became large bleeding sores. When given milk, a quart at a time, by stomach tube for a few days, improvement started at once; by the end of the experiment it was eating all its food, the skin had healed, and new hair was growing.

The post-mortem examination revealed marked congestion in all the viscera, especially in the mesenteric vessels. The stomach was greatly distended, the mucosa somewhat swollen and containing a few pin-point to pin-head sized haemorrhages. In a few

animals the intestinal mucosa contained a few small greyish superficial ulcers. Intestinal contents were greenish in colour and contained no blood or mucus. The liver showed extensive tissue changes consisting of congestion, central necrosis and fatty infiltration. The kidneys were pale and soft, the principal site of damage being the convoluted tubule, although the glomerular tufts were also sometimes swollen.

According to reports in the German literature of the last few years, diseases are making their appearance which have hitherto been unknown on the Continent. Gonnermann attributes the increasing number of disturbances of metabolism and also the increased incidence of amenorrhœa to aluminium in food. In his opinion the large quantity of aluminium found, amongst the German population, in different parts of the body in recent years is due to the fact that unusual amounts of alum were of necessity given in food during the War.

Considering the more extensive use of aluminium utensils in the households abroad, the increasing incidence of disease is not surprising, and the results obtained from a comparison between the health conditions in this country during the last ten years and those on the Continent previously are no longer valid. It is therefore interesting to learn that in Germany too, within the last two years, some diseases have been traced directly to aluminium.

Putensen, in Bavaria, from personal observation on patients describes the signs and symptoms of aluminium poisoning *in practically all details, as reported by me in 1928.* He, too, lays special stress on constipation, flatulence, low blood pressure and giddiness as the main characteristics. Eczema and pruritus as well were observed by him in one patient. Moreover, he describes the case of a dog whose persistent rash and sores associated with intense itching did not respond to local treatment, but disappeared eight days after the aluminium utensils from which the dog was fed were discarded.

Von Halla records 25 cases of patients suffering from severe constipation and dermatoses, which did not yield to any treatment on orthodox lines, but were cured after the aluminium utensils had been removed from their households.

Kazil, in Prague, describes, as the outstanding symptom, diarrhoea followed by severe constipation, colicky pain, neuralgiæ and anaæmia. In post-mortem examinations performed on workers in aluminium factories he observed that the lymphatic glands had become impregnated with minute particles of aluminium, and that this had led to proliferation of the connective tissue and atrophy of the pulp. Similar changes had occurred in the spleen and the bone marrow, and the deposition of aluminium and consecutive irritative action had taken place also in the liver and the glands of generation. The digestive tract showed signs of hyperæmia and mucous catarrh, both of which were of chronic nature.

It would appear impossible, though it has been done in certain quarters, to minimize or to consider as valueless findings which have been arrived at after most careful and painstaking researches. The chemical properties of aluminium seem, however, to be established beyond dispute. *It is readily attacked by acids and soluble in alkalies.*

It is attacked slowly by cold acetic acid, but the rate of attack increases markedly with rising temperature and with progressing dilution of the acid. It is attacked with great rapidity by hydrochloric acid, hydrogen being evolved and aluminium chloride formed. Hydrofluoric acid in all concentrations acts rapidly upon aluminium and its alloys, but lactic acid only slowly. The metal is attacked even by fairly pure atmospheric air, and all the more rapidly by impure air such as that in large industrial cities.

Aluminium is readily soluble in alkalies, alkaline waters and water to which alkalies or soap have been

added. The blackening and corrosion of aluminium kitchen utensils is often traced to alkalies which have come in contact with them.

Chlorine attacks the metal rapidly when dry, and the action is considerably accelerated with increasing moisture content and rising temperature, forming aluminium chloride. Aluminium is quite useless for the handling of the halogens, their acids and salts. Waters with gases in solution and tap waters have slight action, and the solution rate of aluminium in tap waters varies according to the constitution of the water. Both aluminium and its alloys are attacked by sea or salt water. Immersed in water it becomes corroded, the corrosion producing blistering and scaling. Chemical analyses have shown the blisters to consist of aluminium hydroxide plus calcium oxide and silica. The last two constituents were always found in the efflorescence on the metal that had been corroded by tap water or other solutions.

The ordinary analysis of the aluminium metal and its alloys calls for the determination of copper, iron and silicon as impurities, and the remainder is said to be aluminium. This ordinary *incomplete* analysis is, however, inadequate in so far as it omits other elements which we may expect to be present in aluminium utensils, since signs and symptoms known to be produced by such elements have disappeared promptly after the utensils have been discarded.

As the metal is attacked by such a variety of different materials, it would not be surprising to expect that, in the process of preparing food, the constituents of the aluminium alloys and also their inevitable impurities should be set free, so as to contaminate the food. It is outside the scope of this paper to discuss metals, such as *copper, iron, zinc, lead, tin, etc.*, which are found in the utensils as essential constituents of the alloys or as impurities. In the discussion, however, of the dangers arising from the use of aluminium for cooking purposes, a few of the other elements present must be

considered. They have so far completely escaped attention.

(2) FLUORINE.

Among the symptoms described above, one in particular occurred very frequently, namely acroparesthesiae affecting mainly the hands and more especially the fingers supplied by the dorsal cutaneous branch of the ulnar nerve, that is to say the inner side of the little finger and the adjacent sides of the ring and little fingers. This last sensation was experienced on many occasions in self-observation.

There is to my knowledge one poison only which affects the ulnar nerve (just as lead affects the radial nerve), namely fluorine and its salts, which also produce gastro-intestinal symptoms, urticaria, low blood pressure and albuminuria. It will be remembered that all these signs and symptoms were met with very frequently, forming an essential part of the symptom-complex. Attention has already been drawn to the fact, demonstrated by Siem, that hypopiesis is also one of the effects of poisoning by the element aluminium.

It has been shown that cryolite, which after purification contains, amongst others, 50% fluorine and 30% sodium, is used as an indispensable material in the dissolving of bauxite and it is to be suspected that fluorine and its compound NaF may be present in the metal as one of the impurities.

Sodium fluoride produces severe disturbances if doses of 10-12 mg. (about $1/5$ gr.) are taken over a long period. Its toxic action consists in its ability to precipitate calcium salts stored in the body as a material indispensable for sustaining the vitality of most of the organic functions, and to substitute sodium or potassium for the calcium which has been removed. The salts of hydrofluoric acid act then in exactly the same way as those of phosphoric, oxalic and oleic acids, namely by producing damage indirectly. Only thus can it be explained why injection of calcium chloride not only

saves animals which otherwise would be doomed to certain death, when exposed to fluorine poisoning, but also, when given in time, prevents the development of toxic symptoms. This is also, in my opinion, the reason why calcium preparations given to patients by the mouth, or still better injected intravenously, rapidly alleviate urticaria, so-called "chilblains," various eczemata and allied conditions.

The literature on the subject of fluorine includes a most interesting series of articles by two Swiss investigators, Cristiani and Gautier. A herd of cattle, *kept in the environment of aluminium factories and feeding on fodder exposed to the gases emanating from these factories*, all perished within a very short time, after having suffered from a disease diagnosed by veterinary surgeons as Osteomalacia, since spontaneous fractures of the bones were one of the outstanding features of the disease. The investigators achieved precisely the same disease picture by feeding animals on fodder exposed experimentally to hydrofluoric and fluosilicate acids or by administering fodder to which salts of these acids had been added. The disease picture was so typical that they suggested for it the appropriate name of "fluorosis."

By daily peroral administration of fluorides in quantities up to 0.4 g. Rost succeeded, in his experiments on dogs, in producing, besides osteoporosis, which is a common effect of fluorine poisoning, other severe disturbances of bone-formation and exostoses.

(3) SILICA.

In describing the signs and symptoms, great importance was attached to the regularity with which a slight reduction of Fehling's solution occurs. *This reduction disappears, with improvement of the general condition, after aluminium utensils and other sources of metallic poisoning have been discarded.* In conjunction with some of the features described in the disease picture (dryness of the throat, pruritus, furunculosis, gastro-

intestinal symptoms, neuritis, etc.) this reduction led in some cases to a hasty diagnosis of diabetes by different medical men, including myself.

It is an established fact that one of the specific effects of poisoning by silica and its salts is glycosuria and acetonuria, the others being albuminuria, traces of blood in the urine and gastro-intestinal disorder.

Silica, as has been pointed out above, is one of the constituents of bauxite (7%), of cryolite (0.25-0.50%) and of the electrodes. Moreover, it must be borne in mind that the aluminium-copper-silicon alloy is often used in the production of cooking utensils, and the possible presence of silicon should therefore be suspected in the utensil.

(4) FERRO-SILICON, ARSENIC AND ANTIMONY.

The silicon may be mixed with iron, contained as an impurity in the aluminium, forming ferro-silicon, a compound which contains phosphorus and arsenic and, on exposure to moisture, develops phosphoretted hydrogen (Phosphine, PH_3) and arseniuretted hydrogen (Arsin, AsH_3). In addition, it is a well-known fact that arsenic and antimony are invariably present as impurities in several metals. The latter was mentioned above as being present in the aluminium-bearing scraps from which "secondary" aluminium is produced. Emphasis has also been laid on the similarity in the actions of aluminium and arsenic. This suggestion, as far as I know, the first ever put forward, is borne out by Underhill and Peterman, who reject the assertion made by others to the effect that aluminium is a physiological metal in the sense that calcium or magnesium is. They are inclined to the viewpoint that it should be classed rather with copper and arsenic.

In 1928, I expressed the opinion, though without being able to give any proofs, that *diverticulosis of the colon*, which is a disease occurring in ever-increasing

frequency, might have some relation to the increased use of aluminium cooking utensils. As early as 1925, however, Odier in Switzerland reported, without adducing any scientific data, that a few persons, hitherto in perfect health, had developed cancer of the digestive tract some months after the introduction of aluminium utensils into their households. He suggested the possibility of *a connection between the alarmingly increasing incidence of cancer and the widespread use of aluminium for cooking purposes*. This suggestion was refuted by Lehmann, Frank and Blumenthal in Germany, and Bordas in France, in each case *without any scientific argument being put forward*. To judge, however, from the observations described in the German literature by two independent observers, Buerstenbinder and Merk, the hypothesis of Odier seems to be gaining ground *as one more theory of the causation of cancer of the digestive tract*. No explanation was put forward by Odier, but it may be fruitful to investigate whether the development of cancer of the gastro-intestinal tract cannot be traced to chronic irritation by the particles of carbon which are present in practically all grades of aluminium utensils as an impurity. They are derived from the carbon lining, made of *petroleum coke with an oil or tar binder*, which constitutes the electrodes that come in contact with the materials used in the furnace during the process of manufacture of aluminium.

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